DMRT Models for Active and Passive Microwave Remote Sensing

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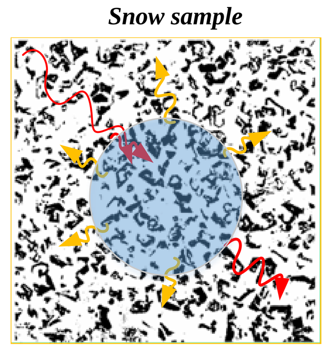
Introduction

Using combined active and passive microwave observations to monitor snowpack has recently drawn lots of attention in the snow remote sensing community. A physical model which can accurately predict backscatter and brightness temperature from snow is of critical importance to interpret the microwave signature and retrieve snow parameters. The partially coherent model of dense media radiative transfer (DMRT) model is introduced with two implementations: 1) the Quasi-Crystalline Approximation of Mie scattering of densely packed Sticky spheres (QCA/DMRT), and 2) Bicontinuous media / DRMT. The defining parameters of sticky spheres and bicontinuous media can be related to measurements through correlation functions[1]. We also discuss the application of the open source code of QCA/DMRT (online) and Bicontinuous Media/ DMRT (appear soon).

Dense Media Radiative Transfer Model

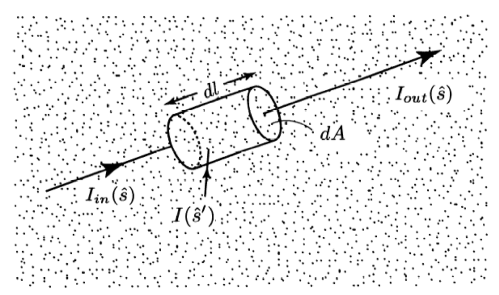
Solve Maxwell's Eq. over a snow sample with QCA or DDA → Substitute into & Solve RTE for backscatter σ and brightness temperature TB

Snow sample



Contain large number of scatters(3~5λ)

- ❑ Coherent near field interaction
- ❑ κ_s has weaker frequency dependence than independent scattering
- ❑ P has more forward scattering than Rayleigh phase matrix



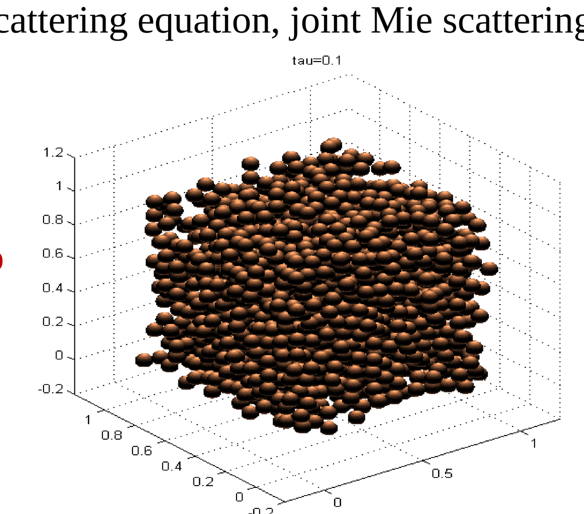
κ_e:extinction coefficient
κ_a:absorption coefficient
$P(\hat{s},\hat{s}')$:Phase matrix

$$\frac{dI(\hat{s})}{ds} = -\kappa_e I(\hat{s}) + \int d\hat{s}'\, P(\hat{s},\hat{s}') I(\hat{s}')$$

Densely Packed Sticky Sphere and QCA

❑ QCA is an analytic solution of Foldy-Lax multiple scattering equation, joint Mie scattering with pair distribute function.

- Input:
  - r_g:grain size (diameter) f_v :volume fraction
  - τ:stickiness parameter **Adhere together to from aggregation**
- **Pair distribute function**:$g(\bar{r}_m - \bar{r}_n)$ describes joint probability of two particle position
- From pair distribute function can derive correlate function



Densely Packed Sticky Spheres

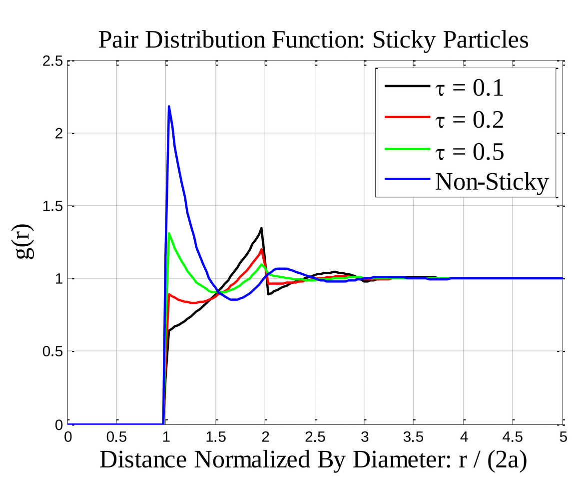


Fig. 1. Pervus-Yevick pair distribution functions, volume fraction 30%, grain size 2.0mm

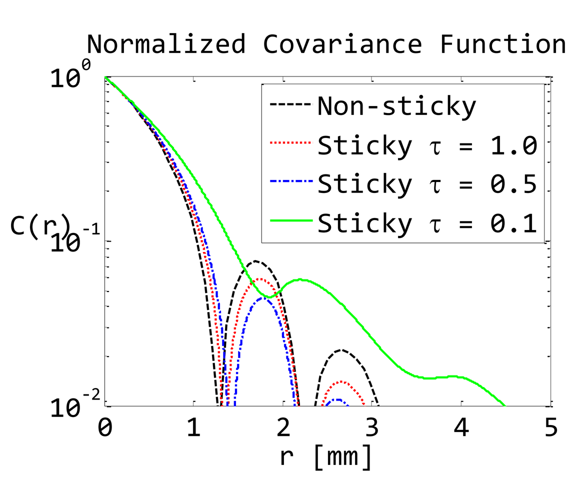


Fig. 2. Covariance functions, volume fraction 30%, grain size 2.0mm

Bicontinuous Media

Random function:

$$S(\bar{r}) = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} \cos(\bar{\zeta}_n \cdot \bar{r} + \varphi_n)$$

Cutting level

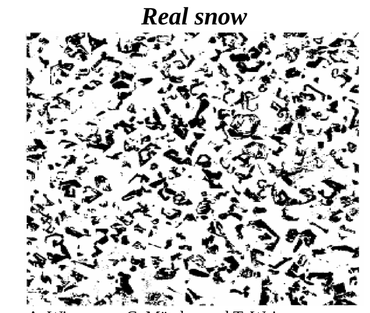
$$\Theta_\alpha[S(\bar{r})] = \begin{cases} 1(ice), & S(\bar{r}) \ge \alpha \\ 0(air), & S(\bar{r}) < \alpha \end{cases}$$

α: $f_v = \frac{1}{2}[1 - \text{erf}(\alpha)]$

$\langle\zeta\rangle$: inversely proportional to grain size

b: determine size distribution

Real snow



A. Wiesmann, C. Mätzler, and T. Weise, "Radiometric and structural measurements of snow samples," *Radio Sci.*, vol. 33, pp. 273-289, 1998.

❑ The 3-D numerical solutions of Maxwell equation are calculated using discrete dipole approximation (DDA) for Bicontinuous model.

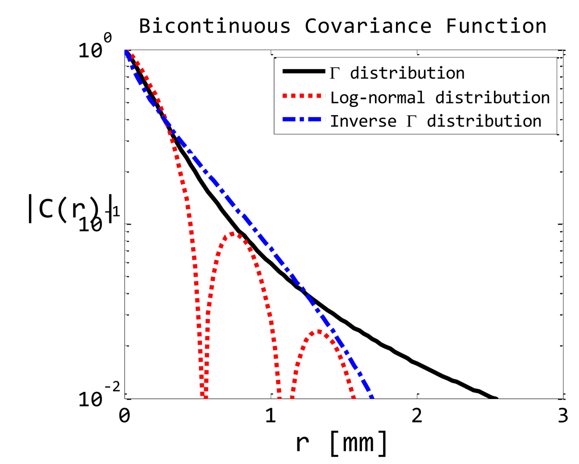
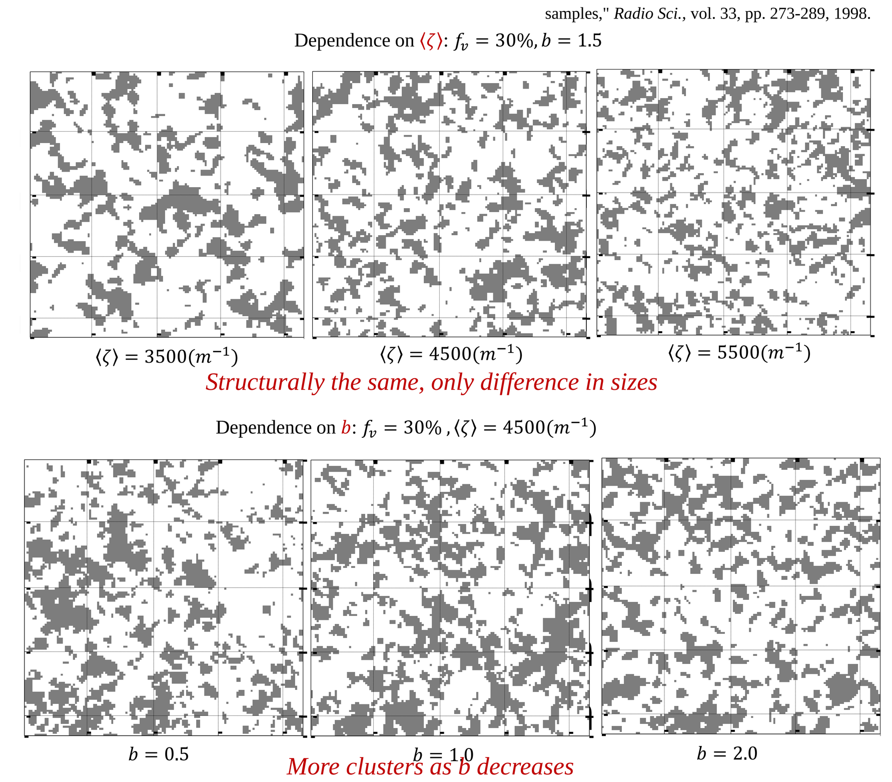


Fig. 3. Covariance functions with three type of size distribution



Bi-continuous snow model

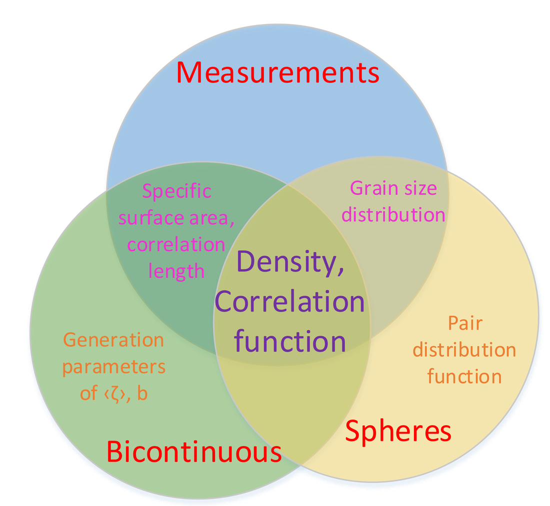
Snow Microstructure Characterization

❑ Snow is a two phase dense random medium, which is characterized by indicator function

$$\Theta(\bar{r}) = \begin{cases} 1, \text{for } \bar{r} \text{ in ice} \\ 0, \text{for } \bar{r} \text{ in air} \end{cases}$$

❑ Correlation function

$$C(|\bar{r}_1 - \bar{r}_2|) = E[\Theta(\bar{r}_1)\Theta(\bar{r}_2)]$$



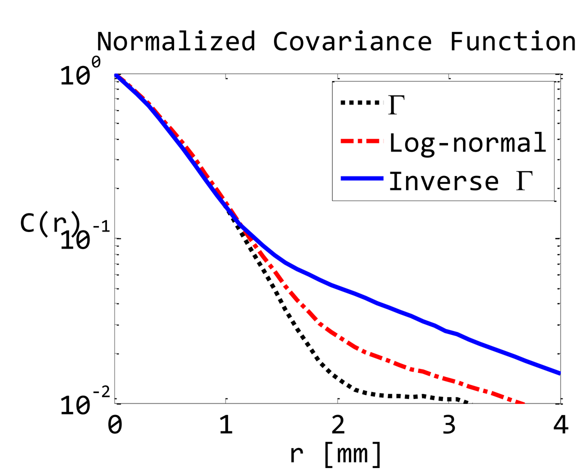


Fig. 4. Covariance functions with three type of size distribution

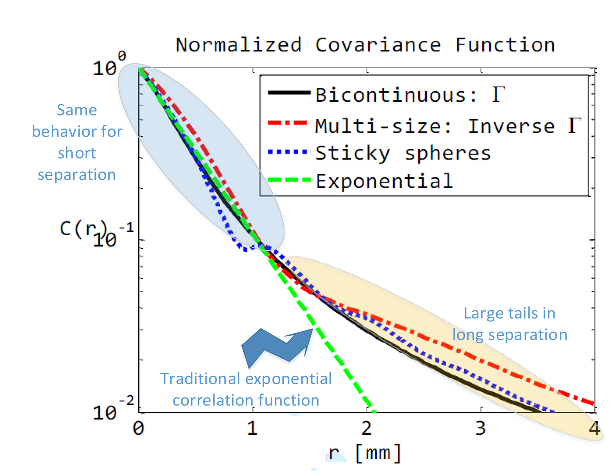


Fig. 5. Covariance functions of QCA multi size, QCA sticky and bicontinuous model

- ❑ Correlation functions are close to exponential for short correlation distances
- ❑ Tails in covariance functions at larger distance indicates large grain aggregation with non-Rayleigh scattering.
- ❑ Traditional expotential correlation functions ignore the tails

Validation with Measurement

ESA CoReH2O at Sodankylä, Finland (NoSREx): Tower based time series measurements[3]

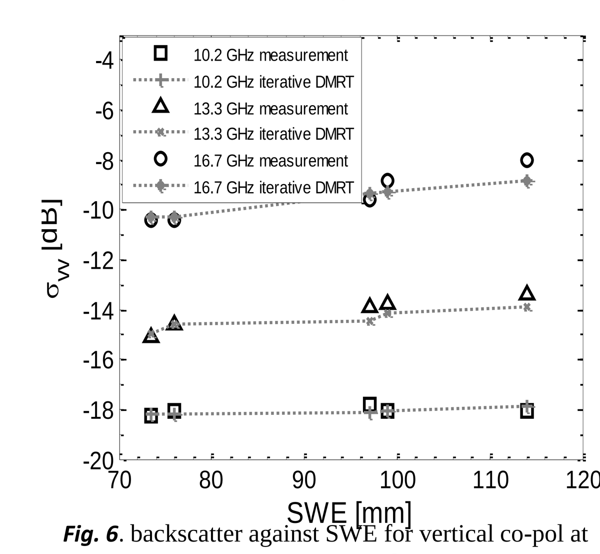


Fig. 6. backscatter against SWE for vertical co-pol at 10.2GHz, 13.3GHz, and 16.7GHz

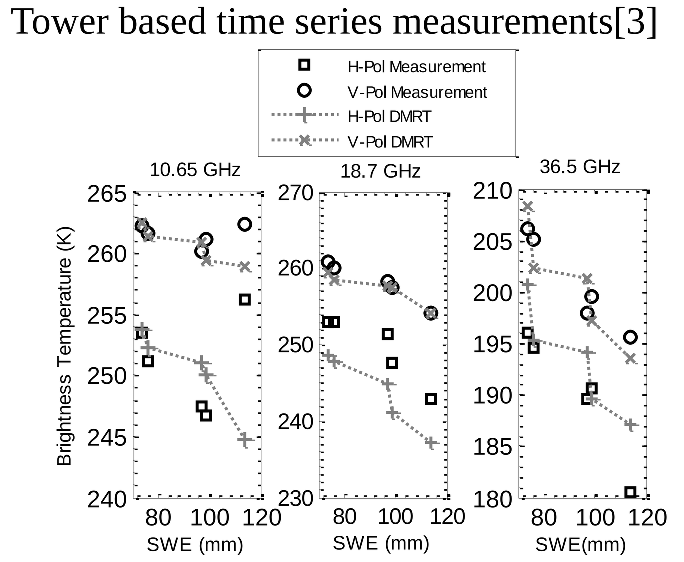


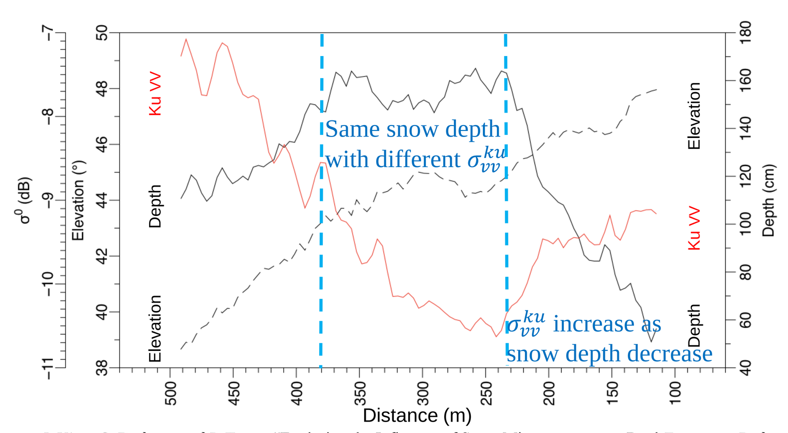
Fig. 7. brightness temperature against SWE at (a) 10.65GHz, (b) 18.7GHz and (c) 36.5GHz

- ❑ Same set of physical parameters used in forward model
- ❑ Bicontinuous DMRT model match all six channels, for both active and passive
- ❑ Positive correlation of backscatter with SWE at 13.3 and 16.7 GHz

Open Source

❑ QCA/DMRT and Bicotinuous Media/DMRT open source code is available online.
http://web.eecs.umich.edu/~leutsang/Computer%20Codes%20and%20Simulations.html

- Measurement



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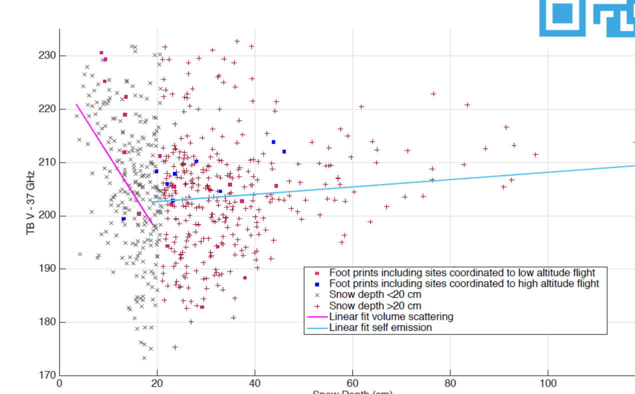

N.Saberi, R. Kelly, C.Derksen, and P.Toose, "Coupling DMRT-ML to a Multi-Scale Passive Microwave Data" *AGU Fall Meeting*, Dec 14-18, 2015.

- DMRT-QMS

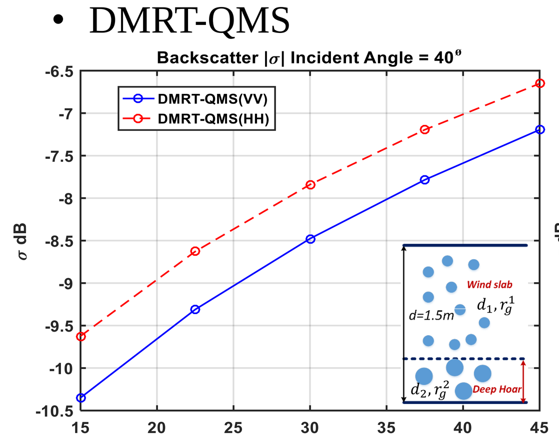

Fig.8 Two layer QCA model, with fixed snow depth 1.5m, σ_{vv}^{ku} vary with deep hoar thickness
freq:17.2GHz,$f_v^1 = 0.3, f_v^2 = 0.25, \tau_1 = 0.5, \tau_2 = 0.2, r_g^1 = 0.8mm, r_g^2 = 1.5mm, T_s = 260K, T_g = 270K$

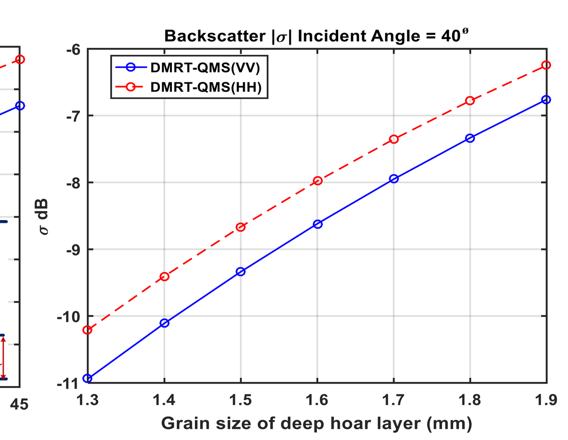

Fig.9 Two layer QCA model, with fixed snow depth 1.5m, σ_{vv}^{ku} vary with r_g^2
freq:17.2GHz,$f_v^1 = 0.3, f_v^2 = 0.25, \tau_1 = 0.5, \tau_2 = 0.2, r_g^1 = 0.8mm, d_2 = 30cm, T_s = 260K, T_g = 270K$

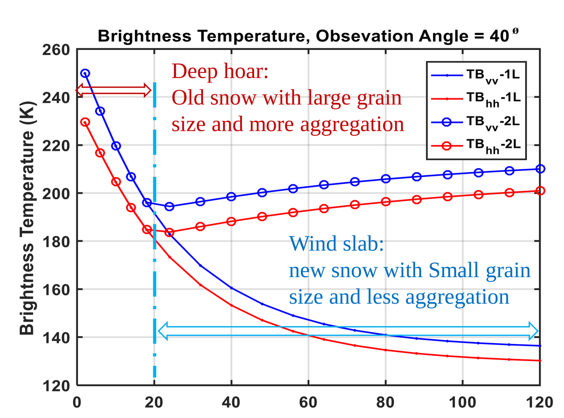

Fig.9 Two layer QCA model, with fixed deep hoar thickness, TB vary with snow depth
freq:37.0GHz,$f_v^1 = 0.3, f_v^2 = 0.3, \tau_1 = 0.5, \tau_2 = 0.3, r_g^1 = 0.8mm, r_g^2 = 1.5mm, T_s = 260K, T_g = 270K$

References

[1] W. Chang, K.-H. Ding, L. Tsang, and X. Xu, "Microwave Scattering and Medium Characterization for Terrestrial Snow with QCA-Mie and Bicontinuous Models: Comparisons Studies," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 6, pp. 3637-3648, Feb. 2016.

[2] K.H. Ding, X.Xu, and L. Tsang, " Electromagnetic Scattering by Bicontinuous Random Microstructures with Discrete Permittivities, " *IEEE Trans. Geosci. Remote Sens.*, vol.48, no.8, pp.3139-3151, Aug. 2010.

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